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CHRONIC ISCHAEMIC HEART DISEASE

Transthoracic Doppler echocardiography (TTE) is the preferred tool for the diagnosis and follow-up of patients with chronic ischaemic heart disease. TTE enables repeated study of global and regional left ventricular systolic function, left ventricular remodelling and its consequences, analysis of left ventricular filling and assessment of pulmonary pressures. The investigation therefore provides considerable useful information to adjust medical treatment, monitor evolution and assess prognosis. Systematic control of these parameters is useful in patients with abnormal left ventricular systolic function even if no clinical changes have occurred. Conversely, clinical symptoms guide the frequency of Doppler echocardiography controls in patients with good left ventricular function.

Resting Doppler echocardiography

Left ventricular geometry and function (table 1)

Left ventricular morphology. Investigation for left intraventricular thrombus (cf acute coronary syndrome chapter)

The global morphology of the left ventricle is assessed by two-dimensional echocardiography. Ventricular diameters are measured systematically, in M-mode with long axis parasternal or subcostal views.

Global left ventricular remodelling can be assessed by measuring volumes (Simpson biplane rule) and by measuring the sphericity indices obtained in systole and diastole (ratio of maximum length of the left ventricle to its width in the apical view) [1-4].

Left ventricular aneurysm is characterised by deformity of the diastolic outline in an akinetic or dyskinetic area with a thin wall. The functional value of the residual normal myocardium must be stated [5].

The investigation should always seek to identify a left intraventricular thrombus. This is particularly common as a sequela to anterior or apical infarction with an apical aneurysm [6] (table 2).

Left ventricular systolic function

The assessment of regional left ventricular function involves describing akinetic or hypokinetic areas in different views, describing their extent, morphological features and segmental wall thickness. A thin (diastolic thickness <6 mm) and dense appearance of akinetic myocardium indicates fibrous scarring and is highly predictive of lack of viability [7].

Estimation of left ventricular ejection fraction (LVEF) by two-dimensional echocardiography is part of the routine investigation. The resting LVEF is the most important prognostic indicator in patients with chronic ischaemic heart disease and plays an important role in treatment decisions, including consideration for cardiac resynchronisation [8, 9].

Semi-quantitative visual assessment of the LVEF has the major limitation of limited reproducibility, particularly for low LVEF. LVEF is best measured by the modified Simpson biplane method using harmonic imaging. This method also has limitations in detecting the left ventricular endocardium or left ventricular dilatation. Other techniques which are not used routinely improve the repeatability and reproducibility of measurements, such as the use of intravenous contrast agents [10] or real time transthoracic three-dimensional echocardiography, which has recently been introduced [11].

Left ventricular filling pressures (table 3) *(cf recommendations on the echocardiographic assessment of cardiomyopathies)*

Evaluation of diastolic function is essential. This enables filling pressures to be measured and provides prognostic information.

Transmitral flow analysis by pulsed Doppler is performed routinely. An E wave deceleration time of <150 msec and/or E/A ratio of >2 support raised left ventricular filling pressures in the presence of left ventricular systolic dysfunction [12-16]. Other parameters need to be recorded if mitral flow is "normal" in appearance: Ea wave measurement by tissue Doppler at the annulus with calculation of the E/Ea ratio; pulmonary vein flow by pulsed Doppler (Ap-Am time); left ventricular flow propagation during early filling by colour M-mode (Vp).

Functional mitral regurgitation

Functional mitral regurgitation is often found in heart failure. It is dynamic in nature and may increase or reduce as a result of changes in left ventricular size, geometry and load conditions. Left ventricular dilatation causes apical and lateral displacement of the papillary muscles, increasing the papillary muscle — valve annulus distance [17]. Increased tension on the cordae is responsible for valve restriction, apical displacement of the closure point and reduced closure surface area resulting in an increase in the surface area between the mitral cusps and the annulus in mid-systole (area under the tent) and the height of the closure point. These geometrical and contractile changes cause imbalance between the traction and closure forces on the mitral valve. During ventricular systole, the mitral valve is subjected to two competing forces: closure forces which are represented by left intraventricular pressure and by systolic contraction of the annulus (reducing the annulus surface area to be covered by the mitral cusps) and the traction forces which oppose the closure forces by restricting valve movements in systole (and which occur as a result of the force exerted on the mitral cusps by cordae tendineae and by annulus dilatation) [17].

Increase in mitral regurgitation as a result of physical exercise in patients with heart failure adds to restricting exercise capacity and is associated with a poor prognosis [18-20]. These dynamic changes are often accompanied by an increase in pulmonary arterial systolic pressure and are associated with changes in valve geometry and the dynamic nature of asynchronism [21, 22].

Right cavities, pulmonary pressures and right ventricular filling pressures (table 4)

Analysis of the right cavities involves a morphological assessment of the cavities, right ventricle and atrium, pulmonary artery, superior vena cava and suprahepatic veins. Analysis of right ventricular function is particularly useful following a large right ventricular infarction. Right ventricular systolic and diastolic functions are difficult to assess, requiring parameters obtained using two-dimensional echocardiography to be combined with Doppler flow measurements of pulmonary, tricuspid and suprahepatic vein regurgitation flows.

Pulmonary pressures can be measured from the tricuspid regurgitation or pulmonary regurgitation flow (continuous Doppler).

Right atrial pressure (RAP) is defined either empirically (generally 10 mmHg) or from the diameter of the inferior vena cava (IVC) and its respiratory variations.

Transoesophageal echocardiography is not used routinely but is useful to assess ischaemic mitral regurgitation.

Stress echocardiography (table 5)

Dobutamine echocardiography

One of the most widely used indications for this technique is the investigation of myocardial viability by stress, particularly dobutamine stress echocardiography although this is however at the cost of increased ventricular arrhythmias if LVEF is <25% [23]. Several types of response have been described as predicting subsequent functional recovery: viability only in the presence of segmental resting asynergy with increase in contractility at low doses (protocol limited to low dose or load): a biphasic response, representing an improvement in myocardial thickening at low dose (or low load in the exercise test) with secondary deterioration in the same territory in response to high doses of dobutamine or high load in the exercise test: and sustained improvement, defined as an improvement in myocardial thickening at low dose or load maintained at high doses or high loads. Documenting contractile reserve, even though not synonymous with cell viability [24], predicts functional recovery after revascularisation with good accuracy, particularly if extensive (>4 segments) [25] and is also a risk marker for cardiovascular events [26]. The optimum time to reassess left ventricular function after revascularisation and the methods for doing this (echocardiography or other imaging methods) are debated. It appears however that functional (and LVEF) reassessment are indicated beyond the 5th month, improvement being seen up to 14 months after revascularisation in one third of cases [27].

Left ventricular diastolic wall thickness measured by MRI or echocardiography [7] is an excellent predictive indicator for functional myocardial recovery (sensitivity 94% and specificity 48%) after revascularisation. Diastolic thickness <6 mm excludes viability with excellent diagnostic accuracy.

The meta-analysis published by Bax [28] compared the diagnostic performance of different imaging methods. This was based on 32 studies which used dobutamine echocardiography, 53 isotopic studies and 20 studies which used positron emission topography (with 18-fluorodeoxyglucose); 11 studies directly compared dobutamine echocardiography with an isotopic technique. The overall sensitivity of low dose or high dose of dobutamine infusion was 81%, with a specificity of 80% and negative predictive value of 89%; for low dose dobutamine echocardiography, sensitivity was 82%, specificity 79% and the

Table 1 Chronic ischaemic heart disease: main parameters to record *to analyse left ventricular morphology and function*.

Parameters	Thresholds/quantification	Technical comments	Value
Segmental Wall motion	Qualitative or semi quantitative scoring scale (cf table)	16 or 17 segment model (ASE) [1]	Prognostic value of WMSI
	Describe the number of abnormal segments Segmental kinetics score (WMSI) [1]	2 parasternal views, 3 apical view, sub-costal view	
Wall thickness	>6-mm thick: preserved <6-mm: fibrous scaring [7]	Measured in M-mode (difficult)	No reversibility if fibrous scaring (fibrosis)
Left ventricular ejection fraction (LVEF)	Visual analysis (avoid)		Limitation of visual estimation
	Modified Simpson biplane method (disc summation method) [1]	Harmonic imaging Apical 4 and 2 cavity views	Reference method Limitations: — risk of under-estimating volumes — limited to 2 planes (use of real time 3D)

ASE: American Society of Echocardiography; WMSI: Wall motion score index.

Table 2 Chronic ischaemic heart disease: other essential parameters to record.

Parameters	Thresholds/ quantification	Technical comments	Value
Mitral regurgitation (MR)	State presence or absence of MR, even if mild and mechanism	Colour Doppler, apical approach	
	Threshold for significant MR: ERO >20 mm^2 [17]	Quantification by PISA or Doppler volumetric techniques	Adverse prognostic value in the absence of pre-existing valve disease
Investigation for thrombus	State dimensions and features (sessile or pedunculated)	Harmonic imaging Apical views showing the apex	False positives and negatives diagnosis possible
Cardiac output	Low output <2.2L/min/m^2	left ventricular outflow tract output	Haemodynamic consequence
Pericardium	Topography and volume if effusion	Multiple views	Signs of intolerance (cavity collapse, respiratory flow variations)

PISA: proximal isovelocity surface area; ERO: effective regurgitant orifice

Table 3 Chronic ischaemic heart disease: essential parameters to record *to analyse left ventricular filling* [12-16].

Parameters	Thresholds/quantification	Technical comments	Value
Mitral flow (at valve tip)	Type 1: relaxation abnormality (E/A <1 before 50 years old and <0.5 after 50 years old	Filling flow has multi-factorial dependency (age)	If LVH absent suggests filling pressures not raised
	Type 2: pseudo normal	Use other indices (E/Ea, E/Vp, Pulmonary venous flow)	
	Type 3: restrictive E/A >2 and/or EDT <150ms		If LVEF reduced suggests raised filling pressures
Tissue Doppler at annulus	E/Ea <8	Suggests filling pressures not raised	
	E/Ea >15	Suggests filling pressures raised	In post infarction, independent prognostic value (mortality)

E: transmitral E wave; Ea: tissue Doppler E wave at annulus; LVEF: left ventricular ejection fraction; LVH: left ventricular hypertrophy; EDT: E wave deceleration time; Vp: colour M-mode propagation velocity.

negative predictive value 83%. For high dose dobutamine echocardiography (investigation for biphasic response or sustained improvement), the corresponding values were 79, 85 and 90%. For thallium myocardial scintigraphy with reinjection, the values were 88, 50 and 83% respectively and for positron emission tomography, 93%, 58% and 86% respectively. This meta-analysis confirmed that the isotopic techniques are significantly more sensitive than dobutamine echocardiography although the echocardiography method has higher specificity and negative predictive value (p<0.005). The impact of documenting viability on indications for revascularisation and prognosis were described in the meta-analysis by Allman [26]. This included 24 studies on a total of 3088 patients who were examined by dobutamine echocardiography (n=7), thallium myocardial scintigraphy (n=6) or positron emission tomography (n=11). LVEF ranged between 25 and 31% and viability was found in 42% of cases; 35% of patients underwent revascularisation with an average follow-up period of 25 months. The mortality rate was significantly lower in the group with viability when revascularisation was performed (mortality rate 3.2%/year compared to 16%/year, p<0.0001, reduction in relative risk 79.6%). There was no significant difference in the annual mortality rate in the patient group with no detected viability (6.2 and 7.7%/year respectively). The annual mortality rate in the group which underwent revascularisation was 3.2% with viability compared to 7.7%/year without viability. This rose to 16%/year in the medically treated group with viability compared to 6.2%/year without, highlighting the "loss of

Table 4 Chronic ischaemic heart disease: essential parameters to record *for the right heart*.

Parameters	Thresholds/ quantification	Technical comments	Value
RV kinetics and function	RV wall kinetics RV dilatation (RV/LV diameter ratio >0.6)	Parasternal (short axis) apical (4C) and subcostal views	
Pulmonary ejection flow	Pulmonary output Acceleration time Calculation of resistances [31]		
Pulmonary regurgitation Doppler flow	PHT and Vmin/Vmax of PR PAPm and PAPd	Coupled Doppler and Pedoff probe	PHT (PR) <150 ms and/or Vmin/Vmax <0.5 supports raised RVEDP and prognostic value
Tricuspid regurgitation Doppler flow	TRVmax TR morphology (raised RAP) PAPs Pulmonary resistances	Multiple views and Pedoff probe	Vmax >2.5 m/s (take account age, body surface area)
Inferior vena cava	Diameter and respiratory variations	Subcostal 2D and TM mode	IVC collapse <50% in favor of raised RAP

LV: left ventricle; RV: right ventricle; TR: tricuspid regurgitation; PR: pulmonary regurgitation; PAPs: systolic pulmonary arterial pressure; PAPm: mean pulmonary arterial pressure; PAPd: diastolic pulmonary arterial pressure; PHT: pressure half time; RAP: right atrial pressure; RVEDP: RV end-diastolic pressure; Vmin: minimal velocity; Vmax: maximum velocity; ICV: inferior vena cava.

Table 5 Chronic ischaemic heart disease: optional parameters to record for the left heart.

Parameters	Thresholds/ quantification	Technical comments	Value
Left ventricular morphology			
Sphericity index [4]	L/l ratio [4]	Repeated assessment for remodelling (treatment evaluation protocols)	The lower this ratio the closer the LV appears as a sphere. (normal L/l ratio = 2)
	LV at end-diastole and endsystole divided by the volume of a sphere of identical diameter to the long axis of the LV [4]		
Left ventricular opacification with contrast agent [10]	Harmonic imaging Specific settings for the contrast agent Apical 4 and 2 cavity views	Precise measurement of volumes and LVEF (treatment evaluation protocols)	Improved detection of the endocardium and measurement of volumes and LVEF [10]
Stress echocardiography			
Dobutamine echocardiography	WMSI at different steps LVEF at different steps E/Ea PAPs	Investigation for myocardial viability involving at least 4 segments	Excellent predictive value for functional recovery (NYHA, LVEF) and prognosis No use for mitral regurgitation
Exercise echocardiography	Mitral regurgitation (ERO), RV E/Ea PAPs Area under the tent	Standard protocol, semi-seated on bicycle Zoom on PISA TR (Vmax)	Prognostic value (resting ERO >20mm^2 and Δ exercise ERO >13 mm^2 [20]

E: transmitral E wave; Ea: tissue Doppler E wave at annulus; LVEF: left ventricular ejection fraction; L: length of LV in 4C apical view; l: LV width in 4C apical view; PAPs: systolic pulmonary arterial pressure; PISA: proximal isovelocity surface area; ERO: effective regurgitant orifice; RV: regurgitated volume; TR: tricuspid regurgitation; WMSI: wall motion score index

Consensus indications for Doppler-echocardiography in the diagnosis and follow-up of chronic ischaemic heart disease

Class I

— Assessment of new symptoms or cardiovascular physical signs in a patient with known coronary artery disease.
— Assessment of recovery of left ventricular function after revascularisation
— Repeated echocardiographical assessment of left ventricular function when results are useful to guide treatment.

Class II

— Follow-up in the absence of signs of progression in treated coronary artery disease patients in order to screen for deterioration in left ventricular function.

Class III

— Systematic repeated echocardiography in the absence of a change in clinical state in patients without left ventricular systolic dysfunction.

Consensus indications for exercise or pharmacological stress Doppler-echocardiography in the follow-up of chronic ischaemic heart disease

Class I

— Assessment for changes in symptoms suggesting progression of coronary artery lesions when the exercise test is:
- impossible to perform (orthopaedic problem, arterial disease, elderly patients, etc.);
- uninterpretable (left ventricular hypertrophy, left bundle branch block, etc.);
- negative submaximal and therefore inconclusive;
- equivocal (ST segment depression limited in time and amplitude).

— Detection of restenosis after coronary angioplasty when the exercise test is:
- impossible to perform (orthopaedic problem, arterial disease, elderly patients, etc.);
- uninterpretable (left ventricular hypertrophy, left bundle branch block, etc.);
- negative submaximal and therefore inconclusive;
- equivocal (ST segment depression limited in time and amplitude).

— Identification of the topography and/or extension of myocardial ischaemia to decide on possible myocardial revascularisation.
— Investigation of myocardial viability in the presence of reduced left ventricular systolic function to guide the decision for revascularisation.
— Coronary risk stratification before non-cardiac surgery in intermediate or high risk patients.

Class II

— Exercise echocardiography to estimate the volume and tolerability (pulmonary pressures) of moderate resting mitral regurgitation.
— Dobutamine echocardiography to investigate for myocardial viability in the presence of reduced left ventricular systolic dysfunction to consider the indication for cardiac resynchronisation.

Class III

— Follow-up of a stable coronary artery disease patient able to perform a maximum exercise test.
— Repeated investigation in a stable coronary artery disease patient without other cardiovascular symptoms.

chance" when a decision is taken not to revascularise in the presence of viability; this decision may be taken as a result of coronary anatomy and/or risk factors or co-morbidities.

Exercise echocardiography

Exercise echocardiography has only been used to a limited extent in the investigation of ischaemic left ventricular systolic dysfunction. The two-dimensional imaging acquisition protocol is classical (resting, low load, high load, recovery, for the 2 parasternal and 3 apical views) with additional Doppler acquisitions of the proximal isovelocity surface area of the mitral regurgitation jet (zoom on PISA), the transmitral flow by pulsed Doppler at the annulus and tricuspid regurgitation for measurements of pulmonary artery systolic pressure in the different stages of the exercise test. The degree of mitral regurgitation under baseline conditions does not correlate at all with the changes in mitral regurgitation during exercise, which vary greatly from one patient to the other [18]. An increase in the volume of mitral regurgitation on exercise is seen in almost 80% of cases. A large increase (increase in the effective regurgitant orifice area or ERO >13 mm^2) is seen in almost 30% of cases. When mitral regurgitation is severe at rest (ERO ≥20 mm^2), the incidence rises to 40% and when the leak is moderate it is 25% [26, 28, 29]. The large increase in regurgitated volume is usually accompanied by a significant rise in systolic pulmonary artery pressure and a fall in cardiac output [18]. Increased left ventricular asynchronism occurs in 20-30% of patients and is accompanied by an increase in the severity of mitral regurgitation [21, 30].

The dynamic nature of functional mitral regurgitation has prognostic implications, [18-20], the validated threshold being an increase of ≥13 mm^2 in the ERO during the exercise test. If the increase in ERO exceeds this threshold the relative risk of death is increased by a factor of 5 during a 3 year follow-up period. Analysis of dynamic changes in ERO may inform the effectiveness of medical treatments and guide therapy.

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ACUTE CORONARY SYNDROMES

The acute coronary syndromes (ACS) are a group of various clinical situations ranging from unstable angina to ST segment elevation with myocardial infarction. Echocardiography provides important information in the diagnostic and prognostic assessment of ACS. The versatility of echocardiography instruments into coronary care units and the development of portable echocardiography instruments make this technique the non-invasive imaging method of choice for emergency use, which is readily available and easy to repeat at the patient's bedside.

Conditions for performing the investigation

High quality echocardiography imaging including second harmonic imaging is required in order to obtain a reliable assessment of myocardial wall motion and thickening.

Transthoracic echocardiography (TTE) is sufficient in the great majority of cases to provide diagnostic information and screen for complications. Transoesophageal echocardiography (TEE) is rarely indicated and is used above all if a complication is suspected but is not sufficiently assessed by transthoracic echocardiography. Transoesophageal echocardiography requires a trained operator.

Diagnostic utility

Echocardiography may be a valuable aid if the diagnosis is uncertain, particularly when there is a high index of clinical suspicion of ACS with a normal or non-contributory ECG [1-3]. Echocardiography is generally not useful diagnostically in ACS with ST segment elevation and must not delay the institution of reperfusion techniques.

The development of portable echocardiography instruments allows the diagnosis to be confirmed rapidly if necessary by finding typical regional wall motion abnormalities and to screen for some complications (pericardial effusion, LV thrombosis, right ventricular extension of inferior wall myocardial infarction, mechanical complications) [4].

The parameters to be recorded are predominantly regional wall motion abnormalities. These must be examined systematically in all views. Their topography closely reflects the coronary vascular distribution in the absence of some anatomical variations [5] (figures 1 and 2). The presence of akinesia or severe hypokinesia in a vascular territory is a very sensitive marker of ischaemia [6]. The investigation must be performed using the ASE 16 segment (or 17 segment) classification [7].

The thickness of walls with wall motion abnormalities must be reported. Normal wall thickness argues in favour of an ACS being recent.

Echocardiography is highly sensitive (90-95%), to diagnose ischaemia and infarction in patients with a high probability of ACS [1-3]. It also has a high negative predictive value (approximately 95%). Diagnostic false negatives nevertheless occur in non-Q wave infarction. If ACS is suspected and the ECG is noncontributory the sensitivity of echocardiography to diagnose ischaemia is highest if the investigation is performed during pain, particularly if the wall motion abnormalities regress after the ischaemia is treated.

The positive predictive value of echocardiography to diagnose infarction is lower depending on the likelihood of the diagnosis of ACS being present. Echocardiography must not be used in isolation to diagnose myocardial infarction. Segmental wall motion abnormalities are not specific for infarction or acute ischaemia and may represent post-ischaemic myocardial dysfunction (stunning), infarction scar or non-ischaemic segmental abnormalities such as acute myocarditis.

Echocardiographical assessment of myocardial infarction (ACS with ST segment elevation)

All patients with an acute infarction (with or without ST segment elevation) should have an echocardiogram performed during the hospital phase. In some patients the investigation is performed on an emergency basis for diagnostic purposes, if an infarction is complicated by cardiogenic shock or if a mechanical complication is suspected. In uncomplicated infarction, echocardiography is generally performed after reperfusion treatments. Echocardiography must be performed immediately if a patient develops sudden haemodynamic deterioration. Patients with extensive wall motion abnormalities on the initial echocardiogram are at higher risk of developing complications. Repeated echocardiographic follow-up is indicated in these patients.

Parameters to be recorded [7]

Segmental wall motion

Echocardiography should describe the severity and extent of segmental wall motion abnormalities reporting the number of abnormal segments in the different views, results of examining for segmental abnormalities in the different territories or for signs of previous infarction with wall thinning (table 1). The severity of the wall motion involvement must be reported for each segment, taking into account myocardial thickness: akinesia (no wall thickening or endocardial movement), hypokinesia (reduced wall thickening and endocardial movement), or dyskinesia (paradoxical systolic movement associated with absence of wall thickening).

The ischaemic area may be over-estimated as adjacent segments may experience stretching, stunning or load modifications effects.

Left ventricular morphology

Left ventricular dimensions are usually measured in M-mode in parasternal views. Left ventricular volumes (particularly the end-systolic volume) are measured when the left ventricular ejection fraction (LVEF) is measured using the Simpson method in apical views.

Particular attention should be paid to geometrical changes of expansion of the infarcted area, remodelling or the establishment of an early left ventricular aneurysm.

Left ventricular systolic function

Left ventricular systolic function is assessed by measuring the LVEF using the Simpson biplane method. A segmental wall motion score index (WMSI) is calculated from the sum of the abnormal myocardial segmental kinetics scores as the ratio to